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- What do we have for p+Au collisions?
- What do we still need for p+Au collisions?
- Luminosity projection

What do we have for p+Au collisions?

- RHIC was designed for p+Au collisions
 - Independent rings except DX magnets
 - DX magnets movable (~ 1 shift)
- With stochastic cooling initial Au beam size is at its maximum
 - Allows for DX move in IR6 and IR8 only (~ 1 shift)
- Solutions for lattice, injection and acceleration
 - Lattice takes advantage of stochastic cooling
- Machine with fast setup (beam-based feedbacks), good reliability
- Experience with asymmetric collisions (d+Au, Cu+Au)
- Proton beam with $N_b = 2 \times 10^{11}$, $P = 55\%$
 - with upgrades (OPPIS): $N_b = 3 \times 10^{11}$, $P = 65\%$
- Au beam with $N_b = 1.3 \times 10^9$
 - with upgrades (EBIS/Booster/AGS/RHIC): 2.0×10^9 (emittance?)

$$\text{Run-11: } L_{\text{avg}} = 30 \times 10^{26} \text{ cm}^{-2} \text{ s}^{-1}$$

Luminosity. The collider is designed for a Au-Au luminosity of about $2 \times 10^{26} \text{ cm}^{-2} \text{ sec}^{-1}$ at top energy, while maintaining the potential for future upgrades by an order of magnitude. Operation with the heaviest ions imposes the most demanding requirements on the collider design, and gold-on-gold is taken as the prototypical example. The luminosity is energy dependent and decreases in first approximation propor **Run-12: $L_{\text{avg}} = 10.5 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$ (with $P_{\text{avg}} = 53\%$)** will be higher, with $\sim 1 \times 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$ for pp collisions.

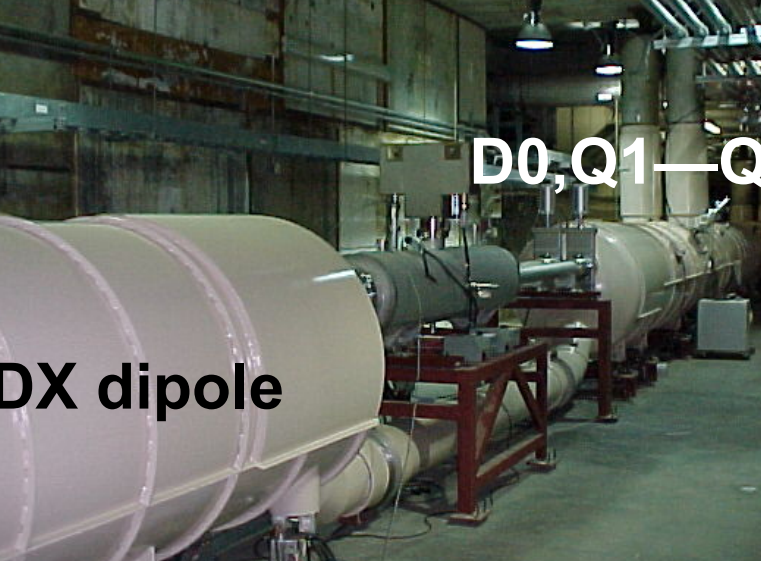
Range of ion masses. The expectations for interesting physics phenomena require a broad range of nuclei from the heaviest to the lightest, including protons. Asymmetric operation with heavy ions colliding on protons is considered to be crucial for the experimental program. The collider will allow collisions of beams of equal ion species from Au-Au all the way down to p-p. It will also allow operation of unequal species such as protons on gold ions.

Uranium is a viable species and can be considered as a future upgrade. However, at the present, an adequate source for uranium does not exist at Brookhaven and further R&D will be needed to achieve this goal.

Intersection Regions. The existing tunnel and the magnet lattice configuration provides for six experimental areas where the circulating beams cross. Three of the experimental areas presently

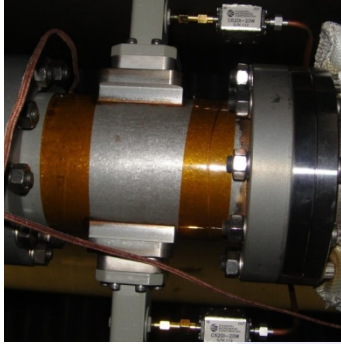
IR design with beam splitting DX dipoles first



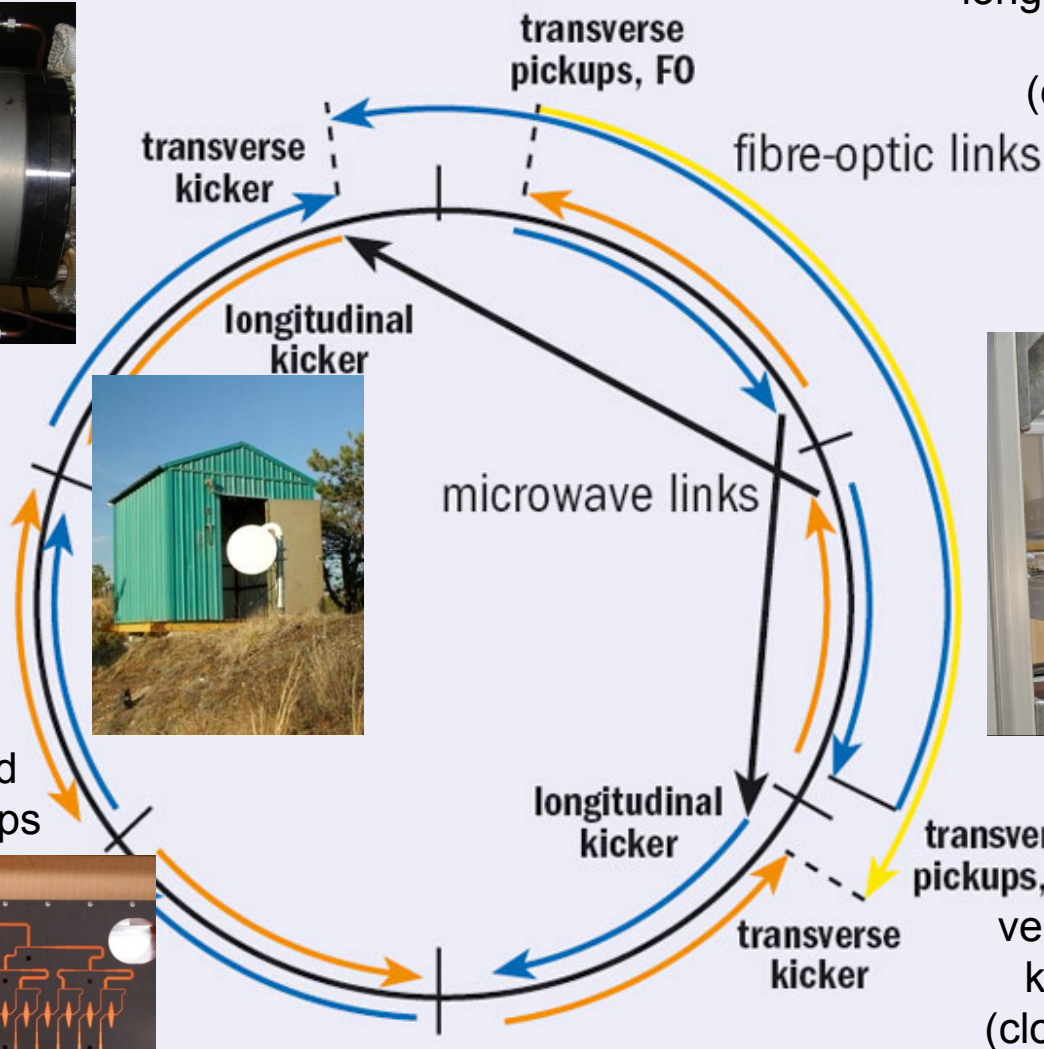
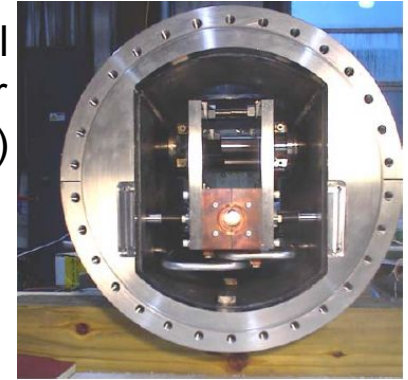
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- DX dipole**
- D0, Q1—Q3**

Now have full 3D stochastic cooling for heavy ions

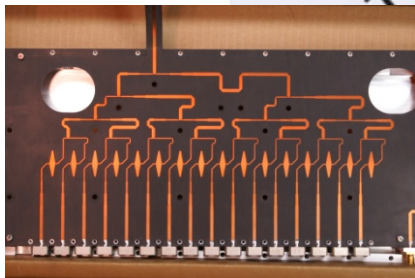
longitudinal pickup



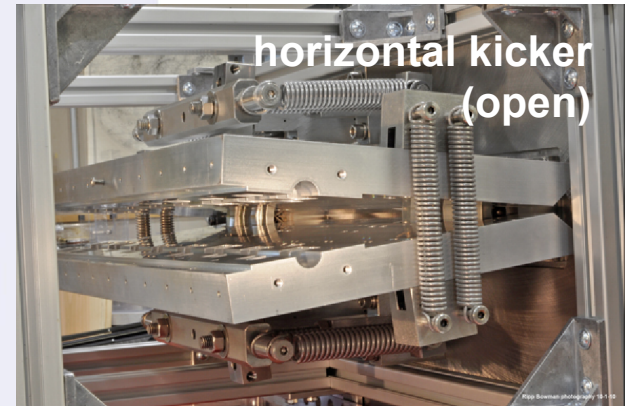
longitudinal
kicker
(closed)



horizontal and
vertical pickups



horizontal kicker
(open)



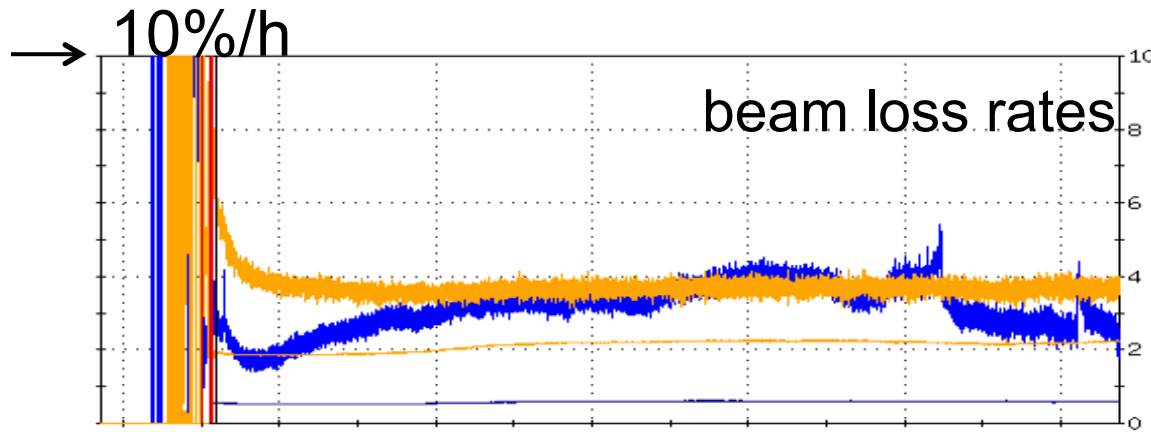
transverse
pickups, FO
vertical
kicker
(closed)



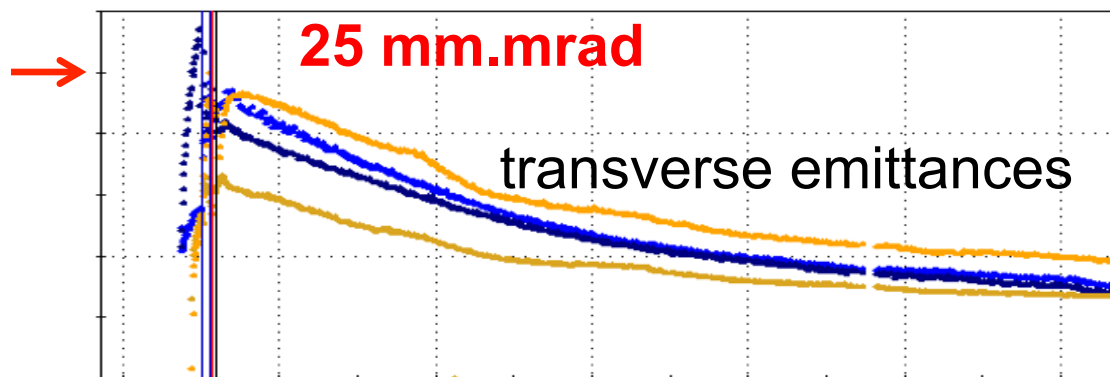
5-9 GHz, cooling times ~1 h

M. Brennan, M. Blaskiewicz, F. Severino, PRL **100** 174803 (2008); PRSTAB, PAC, EPAC

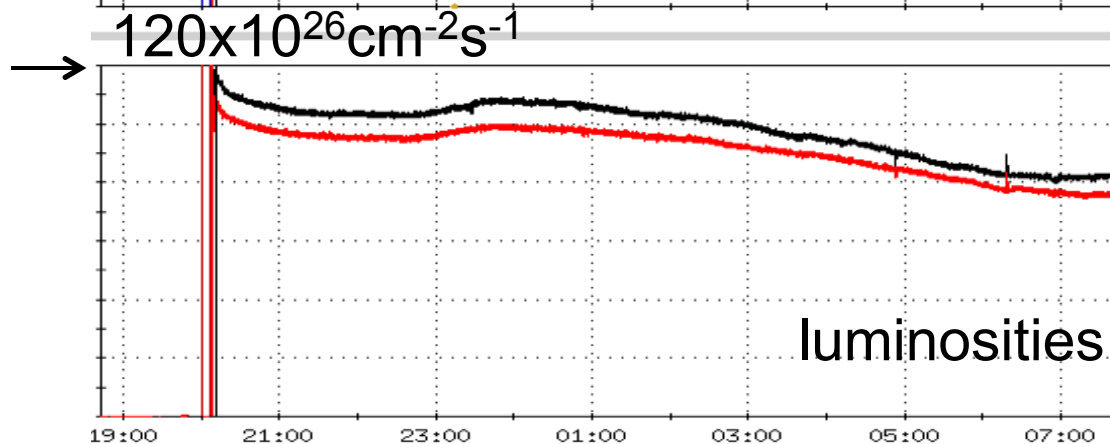
Cu-Au store – new mode in 2012



- Cu and Au have different
- intrabeam scattering growth rates
 $(\sim Z^4 N_b / A^2)$ $r_{\text{IBS,Au}} \approx 2 \times r_{\text{IBS,Cu}}$
 - cooling rates
 $(\sim 1/N_b)$ $r_{\text{SC,Au}} \approx 3 \times r_{\text{SC,Cu}}$



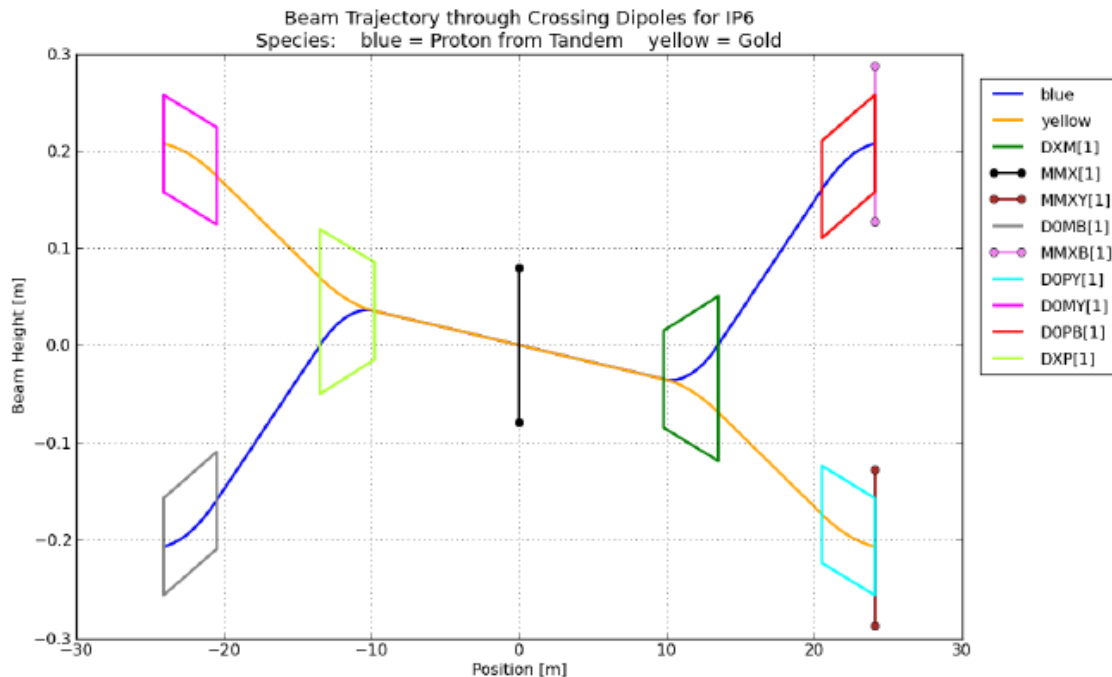
Stores start with large ε
after undergoing instability
at transition



Possible with stochastic
cooling
Increase bunch intensity
until loss at transition

p+Au easier with stochastic cooling

- only need to accommodate initial Au emittances
- sufficient to move IR6 and IR8 DX magnets

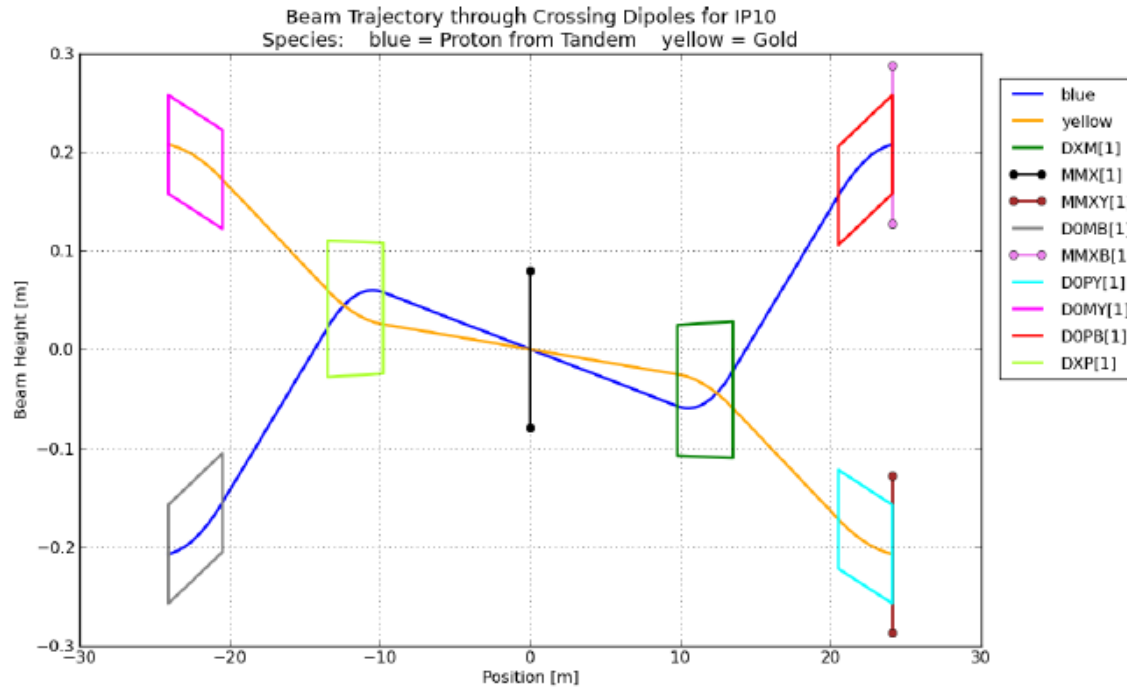


colliding IR
move DX by 1cm

Figure 1. The beam trajectory through the crossing dipoles D0 and DX. The Au beam is 69.4mm from the central line in the DX magnet in the worst case. Additional room for beam size must also be taken into account.

S. Tepikian, D. Trbojevic, C-A/AP/447 (Jan. 2012)

p+Au easier with stochastic cooling



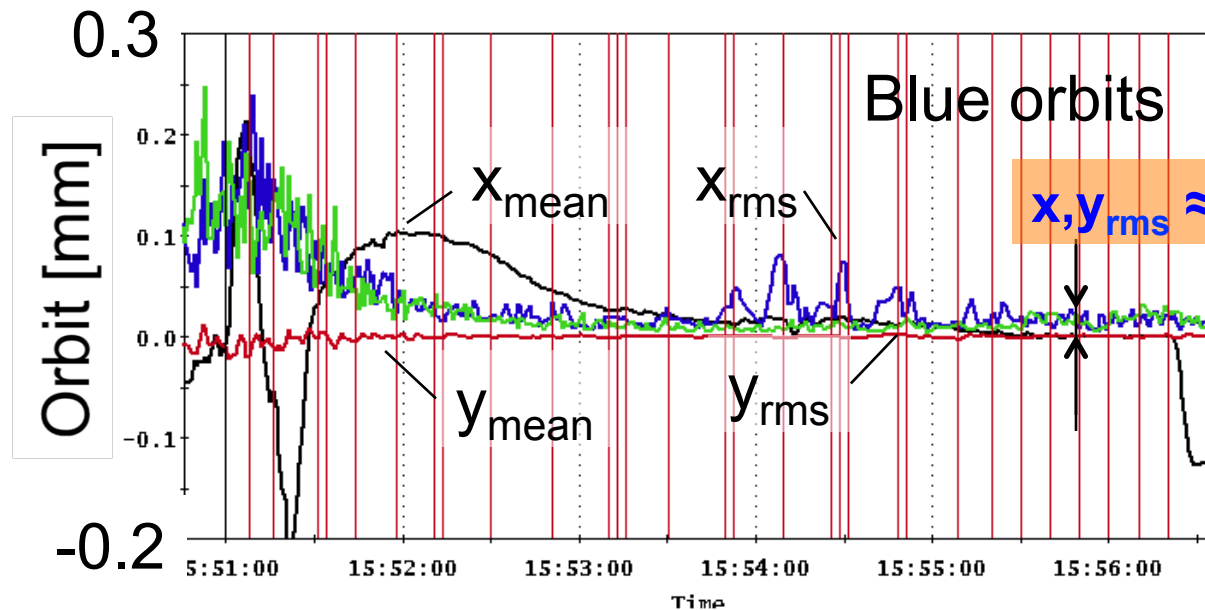
non-colliding IR
no DX move

Figure 2. A non-colliding insertion. The crossing angle is -0.3305 mrad . The beam trajectory is 59.8 mm from the central axes for both beams in the DX magnet. The Blue beam reaches its peak at 10.5 m from the IP, while the Yellow beam reaches its peak at 13.5 m from the IP.

S. Tepikian, D. Trbojevic, C-A/AP/447 (Jan. 2012)

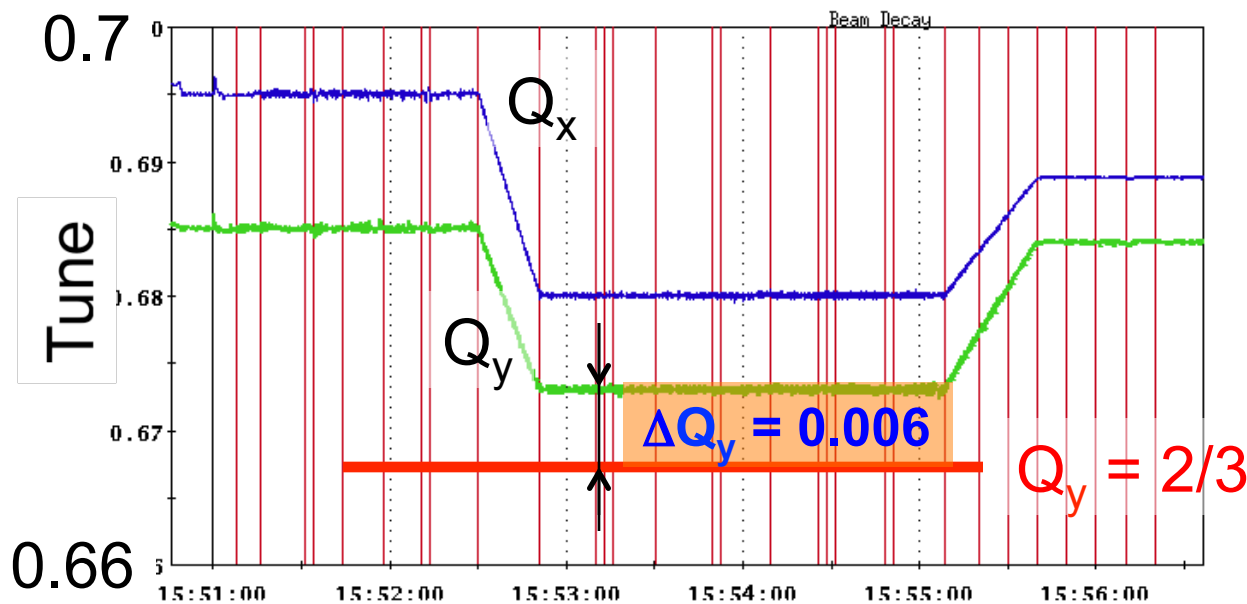
Beam control improvement – feedbacks on ramp

M. Minty,
A. Marusic et al.



Orbit feedback on every ramp allows for

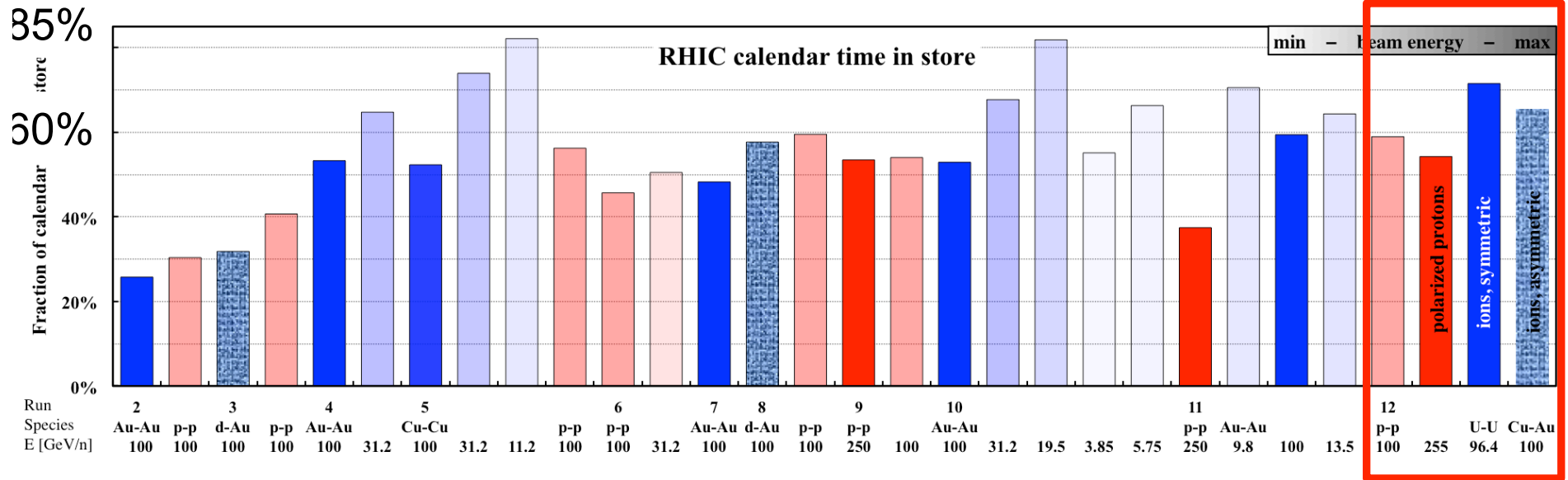
- Smaller y_{rms} (smaller imperfection resonance strength)
- Ramp reproducibility (have 24 h orbit variation)



Tune/coupling feedback on every ramp allows for

- Acceleration near $Q_y = 2/3$ (better P transmission compared to higher tune)

Time-in-store as fraction of calendar time



- Run-12 with low failure rates in all systems
- Highest time-in-store ratios to date
even with increased APEX time during 255 GeV protons, and few weeks per species

What do we still need for p+Au?

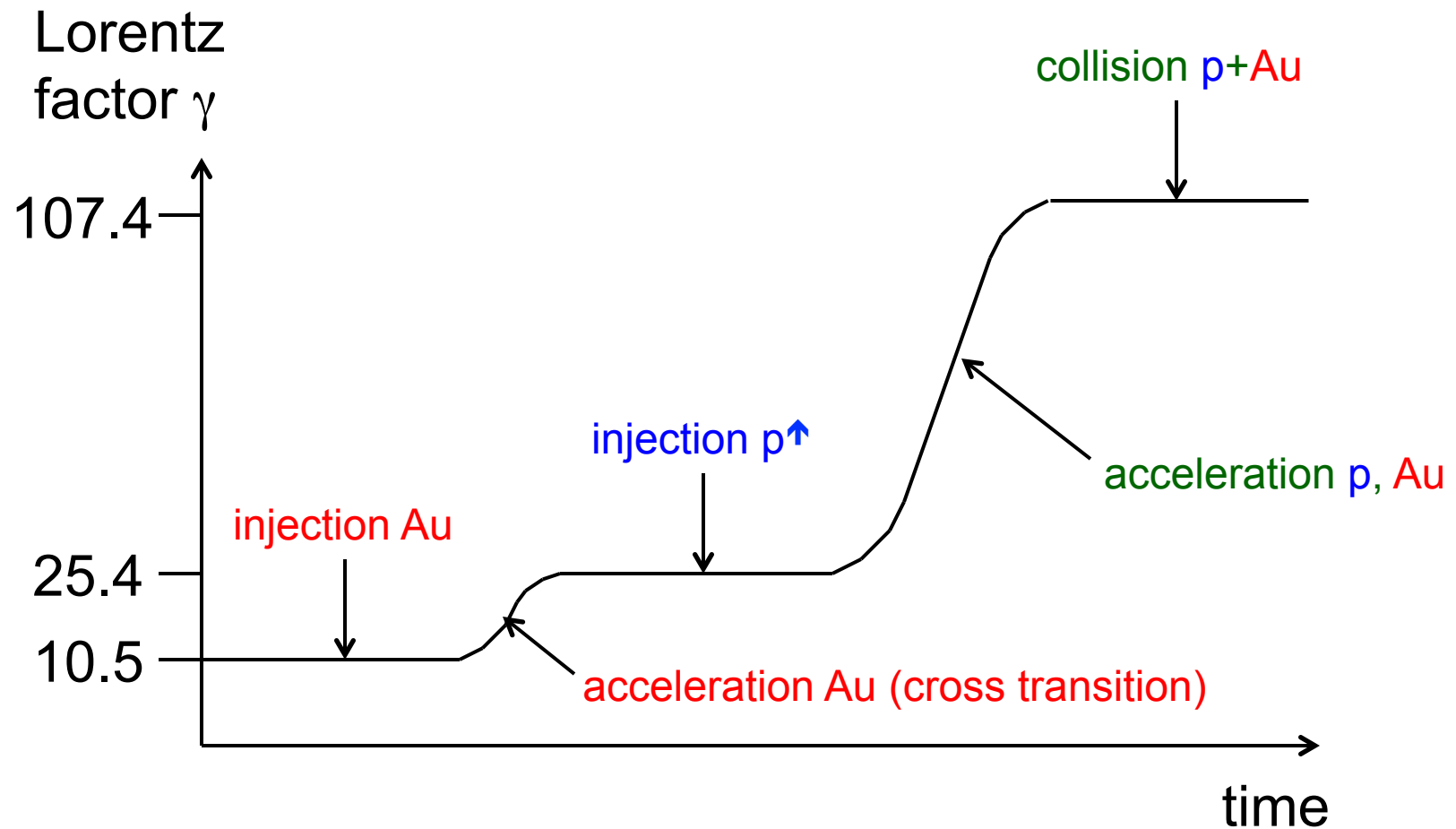
- Demonstrate DX move by 1 cm
 - Can be done at end of Run-13
 - Move for p beam in Yellow, Au beam in Blue (different from d-Au)
- If p beam in Blue is needed (and Au beam in Yellow)
 - Modify vacuum pump stands in IR6 and IR8
 - Modify shielding IR6 and IR8
- Operate with new injection and acceleration scheme
 - Inject and accelerate Au to intermediate level above transition
 - Then inject p and accelerate both beams

Moving IR6 and IR8 DX magnets by 1cm

- Bellows allow for 1 cm movement
- Installed shielding creates tight spaces but acceptable
“6:00 the bellows and ion pump stand were swapped to make space for the shielding, ... cannot be moved because of the ion pump stand” (M. Mapes)
- Easier to do have p in Yellow, Au in Blue (different from d-Au!)

Can be done in ~ 2 shifts (i.e. during a run) when properly prepared in previous shut-down

p+Au injection and acceleration



Note: now tolerate ion beam instabilities at transition obtain higher intensity (can be cooled down again), not possible with p+Au since have smaller aperture available

Asymmetric collisions (p+Au)

- p+Au energies:
100.8 GeV p on 100.0 GeV/nucleon Au ($\gamma_p = \gamma_{Au} = 107.4$)
- For energy scan need to match Lorentz factor γ of both beams

Au-Au history and projections for PHENIX		p	Au	p	Au
Parameter	unit	2013E		2013E	
no of colliding bunches	...	111	111	111	111
ions/bunch, initial	10^9	140	1.0	180	1.4
charges per bunch	$10^9 e$	140	79	180	107
average beam current/ring I_{avg}	mA	194	110	250	148
stored energy per beam	MJ	0.25	0.35	0.32	0.47
transverse rms emittance ϵ_{xy}	mm.mrad	2.9	2.9	2.8	2.8
rms bunch length σ_s	m	0.5	0.3	0.5	0.3
envelope function at IP β^*	m	0.9	0.9	0.7	0.7
beam-beam parameter ξ/IP	10^{-3}	4.3	2.4	5.9	3.1
initial luminosity L/IP	$10^{26} \text{ cm}^{-2} \text{ s}^{-1}$	39		82	
events per bunch-bunch crossing	...				
average / initial luminosity	%	60		70	
average store luminosity L_{avg}	$10^{26} \text{ cm}^{-2} \text{ s}^{-1}$	24		57	
time in store	%	55		55	
max luminosity/week	μb^{-1}			190	
min luminosity/week	μb^{-1}	78			

L_{NN}/week , min/max

pb^{-1}

15

37

Summary

- p+Au is possible
max energy 100 GeV/nucleon for both beams
- Stochastic cooling helps:
DX move only in IR6 & IR8, no Au beam growth
- DX move in ~2 shifts
possible upgrade for pp2pp in IR6 requires change of DX bellows
will reduce flexibility, cannot move DX magnets during run
- New injection/acceleration scheme
store Au beam above transition for ~15 min
- Luminosity estimate based on p[↑] beam available (anticipated),
and Au beam available (anticipated)
 $L_{NN} = 15$ pb/week min (now)
 $L_{NN} = 37$ pb/week max (few years)